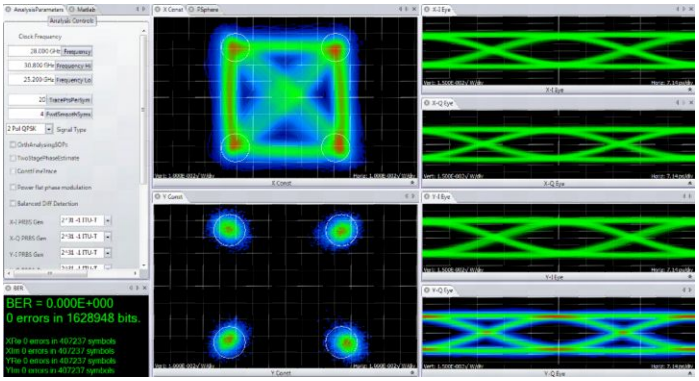
Coherent Lightwave Signal Analyzer Software

OM1106 Software Datasheet



The OM1106 Coherent Lightwave Signal Analyzer software provides an ideal platform for research and testing of coherent optical systems. It offers a complete software package for acquiring, demodulating, analyzing, and visualizing complex modulated systems from an easy-to-use user interface. The software performs all calibration and processing functions to enable real-time burst-mode constellation diagram display, eye-diagram display, Poincaré sphere, and bit-error detection. Advanced users can take advantage of the provided MATLAB signal analysis source code and modify the signal processing algorithms while still taking advantage of the rich user interface for acquisition, signal visualization, and numerical measurements.

Key features

- Complete coherent signal analysis system for polarization-multiplexed QPSK, QAM, differential BPSK/QPSK, and other advanced modulation formats
- Displays constellation diagrams, phase eye diagrams, Q-factor, Q-plot, spectral plots, Poincaré Sphere, signal vs. time, laser phase characteristics, BER, with additional plots and analyses available through the MATLAB interface [1]
- Measures polarization mode dispersion (PMD) of arbitrary order with most polarization multiplexed signals
- Smart polarization separation follows signal polarization
- User access to internal functions with a direct MATLAB interface
- Remote access available through Ethernet
- Superior user interface offers comprehensive visualization for ease-of-use combined with the power of MATLAB
- Multi-carrier software option allows user-definable superchannel setup
- Superchannel configuration allows user to define number of channels, channel frequency, and channel modulation format
- Test automation acquires complete measurements at each channel
- Integrated measurement results allow easy channel-to-channel comparisons

Introduction

A common thread throughout the Tektronix OM-series coherent optical products is the OM1106 Coherent Optical Analysis Software. This software is included with all Tektronix OM4000-series optical modulation analyzers (OMA) and is also available as a stand-alone software package for customers to use with own OMAs or as a coherent optical research tool.

The OM1106 analysis software consists of a number of major building blocks. At the heart of the software is a complete library of analysis algorithms. These algorithms have not been re-purposed from the wireless communications world: they are specifically designed for coherent optical analysis, executed in a customer-supplied MATLAB installation.

The OM1106 software also provides a complete applications programmatic interface (API) to these algorithms. Using these APIs to provide a substantial feature set is the OM-Series User Interface (OUI). The OUI provides a complete coherent optical tool suite allowing any user to conduct detailed analysis of complex modulated optical signals without requiring any knowledge of MATLAB, analysis algorithms, or software programming.

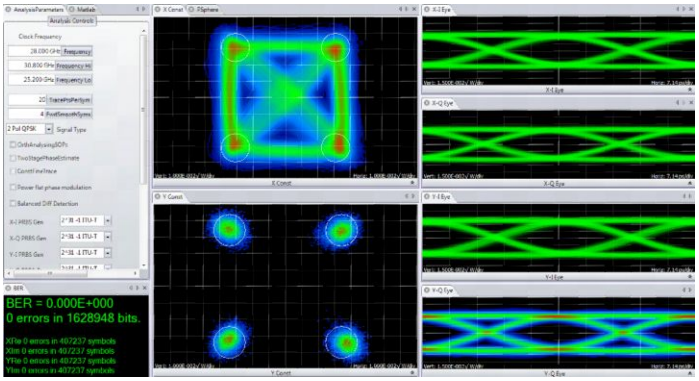
The flexibility of the OM1106 software allows it to be used in a number of different ways. You can make measurements solely through the OUI, you can use the programmatic interface to and from MATLAB for customized processing, or you can do both by using the OUI as a visualization and measurement framework around which you build your own custom processing.

1 MATLAB is a registered trademark of MathWorks.

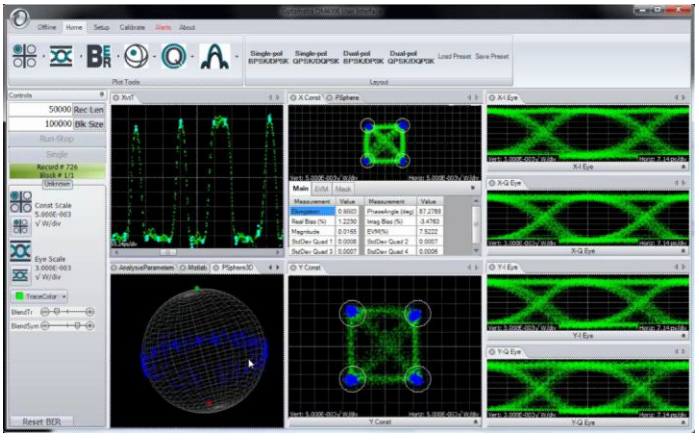
OM-series user interface (OUI)

The common thread through the Tektronix OM-series products is the OM-series user interface (OUI) software that controls the acquisition and display of data. This OUI can be ordered separately without the OM4000-series optical modulation analyzer for analysis purposes with another coherent receiver system. The data-capture and analysis only version of the OUI software is called OM1106.

The OUI provides the user to display all the standard coherent optical visualizations such as eye diagrams, constellation diagrams, Poincaré spheres, and so on. The OUI also provides a complete measurement suite to numerically report key measurements. Constellation measurements include elongation, real and imaginary bias, magnitude, phase angle, EVM, and others. Eye diagram measurements include many key time domain metrics such as eye height, overshoot, undershoot, risetime, falltime, skew, crossing point, etc. Statistics are provided for all numerical measurements to facilitate data gathering over longer periods of time.



OM-series user interface (OUI) showing color-grade graphics options. Symbols can also be colored to a key indicating prior state. Data shown is 112 Gb/s PM-QPSK.

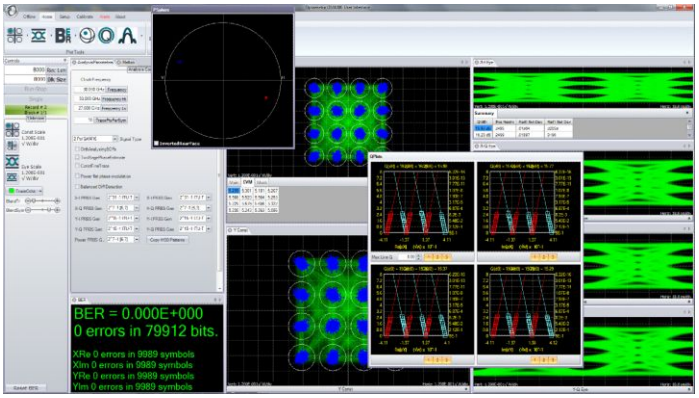


OUI showing display of select equivalent-time measurements.

Get up and running fast with the easy-to-use OUI

The OUI allows you to easily configure and display your measurements and also provides software control for third-party applications using WCF or .NET communication. The OUI can also be controlled from MATLAB or LabVIEW.

The following image shows a QAM measurement setup. The plots can be moved, docked, or resized. You can close or create plots to display just the information you need.



QAM measurements on the OM-series user interface (OUI).

In addition to the numerical measurements provided on the plots, the measurements are also summarized on the Measurements window where statistics are also displayed. An example of some of these measurements is shown in the following figure.

Measurements

Measurement	Value	Mean	Min	Max	StdDev	Count
Xconst Symbol Std. Dev.	0.0886√mW	0.0886√mW	0.0833√mW	0.0912√mW	0.00208√mW	19
Xconst Symbols Displayed	3942	4101	3905	4268	132	19
Xconst Mask Violations	6	6	6	7	0	19
Xconst EVM,Average	8.8 %	8.6 %	8.2 %	8.9 %	0.23 %	19
Xconst Magnitude	1.482√mW	1.439√mW	1.373√mW	1.505√mW	0.03873√mW	19
Xconst Phase Angle	94 deg	90 deg	85 deg	94 deg	3.2 deg	19
Xconst Bias, Imag	-0.12 %	-0.12 %	-0.13 %	-0.12 %	0.0029 %	19
Xconst Bias, Real	-0.011 %	-0.011 %	-0.012 %	-0.011 %	0.00028 %	19
Xconst IQ Imbalance	0.9946	0.9976	0.9534	1.046	0.02677	19
X-I Undershoot	0.79 %	0.75 %	0.72 %	0.79 %	0.023 %	19
X-I Overshoot	0.86 %	0.86 %	0.82 %	0.9 %	0.022 %	19
X-I Falltime	45 ps	47 ps	45 ps	49 ps	1.3 ps	19
X-I Risetime	49 ps	47 ps	45 ps	50 ps	1.5 ps	19
X-I Skew	0.027 ps	0.028 ps	0.027 ps	0.029 ps	0.00082 ps	19
X-I Crossing Point	50 %	50 %	48 %	52 %	1.4 %	19
X-I Rail 1 Std Dev	0.0873√mW	0.0904√mW	0.0863√mW	0.0949√mW	0.00244√mW	19
X-I Rail 0 Std Dev	0.0838√mW	0.0868√mW	0.0828√mW	0.0911√mW	0.00234√mW	19
X-I Eye Height	2.04√mW	2.02√mW	1.96√mW	2.11√mW	0.053√mW	19
X-I Q-Factor	21 dB	21 dB	20 dB	22 dB	0.61 dB	19
X-Q Undershoot	0.71 %	0.73 %	0.69 %	0.76 %	0.021 %	19
X-Q Overshoot	0.85 %	0.87 %	0.83 %	0.91 %	0.025 %	19
X-Q Falltime	47 ps	47 ps	45 ps	50 ps	1.3 ps	19
X-Q Risetime	47 ps	48 ps	45 ps	50 ps	1.3 ps	19
X-Q Skew	0.054 ps	0.056 ps	0.054 ps	0.059 ps	0.0014 ps	19
X-Q Crossing Point	49 %	50 %	48 %	53 %	1.3 %	19

Annotated measurement results table from OUI.

Make adjustments faster

The OUI is designed to collect data from the oscilloscope and move it into the MATLAB workspace with extreme speed to provide the maximum data refresh rate. The data is then processed in MATLAB and the resulting variables are extracted for display.

Take control with tight MATLAB integration

Since 100% of the data processing occurs in MATLAB, test engineers can easily probe into the processing to understand each step along the way. R&D labs can also take advantage of the tight MATLAB integration by writing their own MATLAB algorithms for new techniques under development.

Use the optimum algorithm

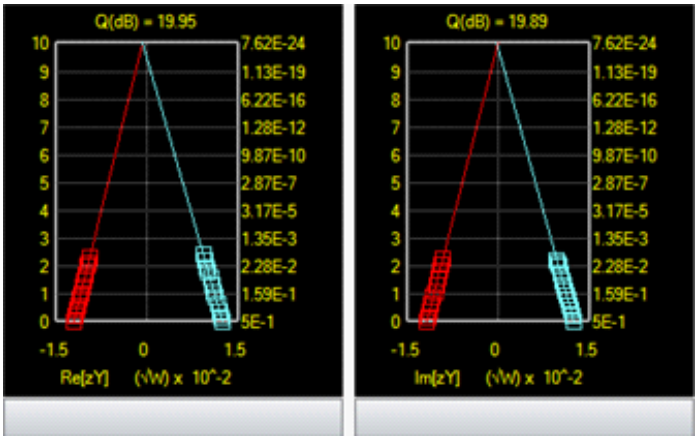
Don't worry about which algorithm to use. When you select a signal type in the OUI (for example, PM-QPSK), the software applies optimal algorithm to the data for that signal type. Each signal type has a specially designed signal processing approach that is best for the application. This means that you can get results right away.

Don't get stymied by laser phase noise

Signal processing algorithms designed for electrical wireless signals don't always work well with the much noisier sources used for complex optical modulation signals. Our robust signal processing methods tolerate enough phase noise to even make it possible to test signals which would traditionally be measured by differential or direct detection such as DQPSK.

Find the right BER

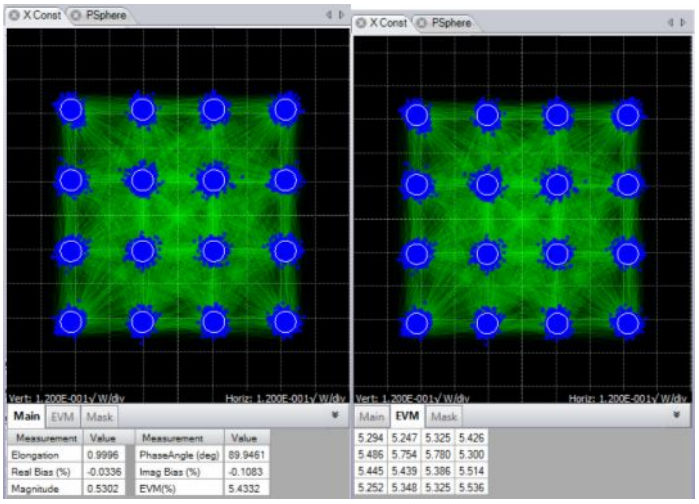
Q-plots are a great way to get a handle on your data signal quality. Numerous BER measurements vs. decision threshold are made on the signal after each data acquisition. Plotting BER vs. decision threshold shows the noise properties of the signal. Gaussian noise will produce a straight line on the Q-plot. The optimum decision threshold and extrapolated BER are also calculated. This gives you two BER values: the actual counted errors divided by the number of bits counted, as well as the extrapolated BER for use when the BER is too low to measure quickly.



Q-plot.

Constellation diagrams

Once the laser phase and frequency fluctuations are removed, the resulting electric field can be plotted in the complex plane. When only the values at the symbol centers are plotted, this is called a Constellation Diagram. When continuous traces are also shown in the complex plane, this is often called a Phase Diagram. Since the continuous traces can be turned on or off, we refer to both as the Constellation Diagram. The scatter of the symbol points indicates how close the modulation is to ideal. The symbol points spread out due to additive noise, transmitter eye closure, or fiber impairments. The scatter can be measured by symbol standard deviation, error vector magnitude, or mask violations.



Constellation diagram.

Constellation measurements

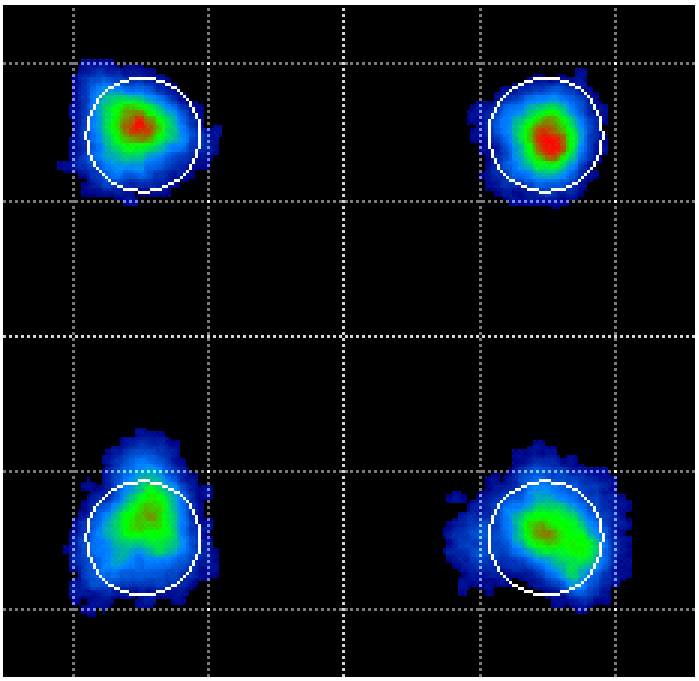
Measurements made on constellation diagrams are available on the “fly-out” panel associated with each graphic window. The measurements available for constellations are described below.

Constellation measurements

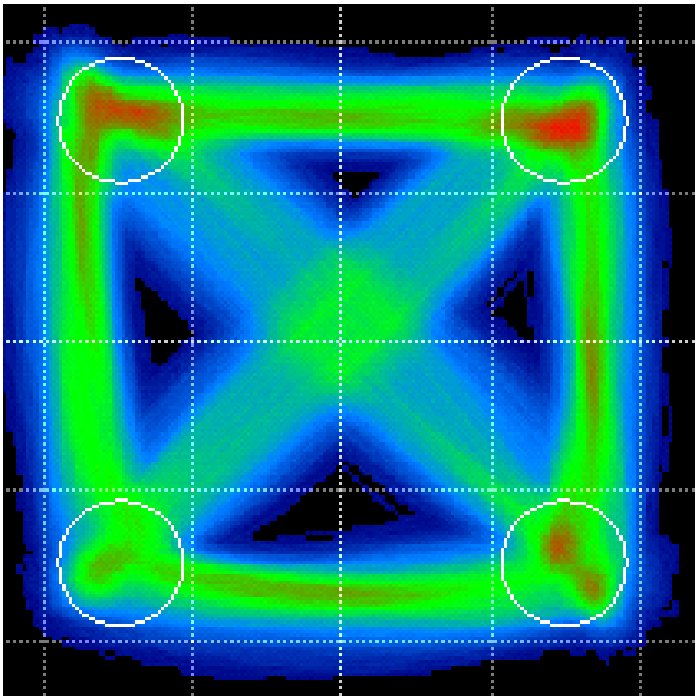
Measurement	Description
Elongation	The ratio of the Q modulation amplitude to the I modulation amplitude is a measure of how well balanced the modulation is for the I and Q branches of a particular polarization’s signal
Real Bias	Expressed as a percent, this says how much the constellation is shifted left or right. Real (In-phase) bias other than zero is usually a sign that the In-phase Tributary of the transmitter modulator is not being driven symmetrically at eye center
Imag Bias	Expressed as a percent, this says how much the constellation is shifted up or down. Imaginary (Quadrature) bias other than zero is usually a sign that the Quadrature Tributary of the transmitter modulator is not being driven symmetrically at eye center
Magnitude	The mean value of the magnitude of all symbols with units given on the plot. This can be used to find the relative sizes of the two Polarization Signals
Phase Angle	The transmitter I-Q phase bias. It should normally be 90
StdDev by Quadrant	The standard deviation of symbol point distance from the mean symbol in units given on the plot. This is displayed for BPSK and QPSK
EVM (%)	The RMS distance of each symbol point from the ideal symbol point divided by the magnitude of the ideal symbol expressed as a percent
EVM Tab	The separate EVM tab shown in the right figure provides the EVM% by constellation group. The numbers are arranged to correspond to the symbol arrangement. This is ideal for setting Transmitter modulator bias. For example, if the left side groups have higher EVM than the right side, adjust the In-phase Transmitter modulator bias to drive the negative rail harder
Mask Tab	The separate Mask tab shown in the right figure provides the number of mask violations by constellation group. The numbers are arranged to correspond to the symbol arrangement. The mask threshold is set in the Engine window and can be used for pass/fail transmitter testing

Color features

The Color Grade feature provides an infinite persistence plot where the frequency of occurrence of a point on the plot is indicated by its color. This mode helps reveal patterns not readily apparent in monochrome. Note that the lower constellation groups of the example below have higher EVM than the top groups. In most cases this indicates that the quadrature modulator bias was too far toward the positive rail. This is not evident from the crossing points which are approximately correct. In this case an improperly biased modulator is concealing an improperly biased driver amp.

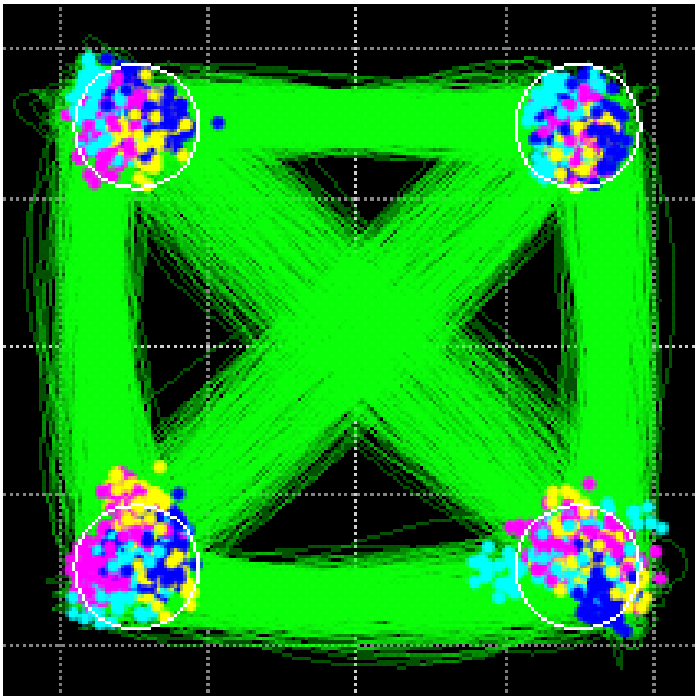


Color Grade Constellation.



Color Grade with fine traces.

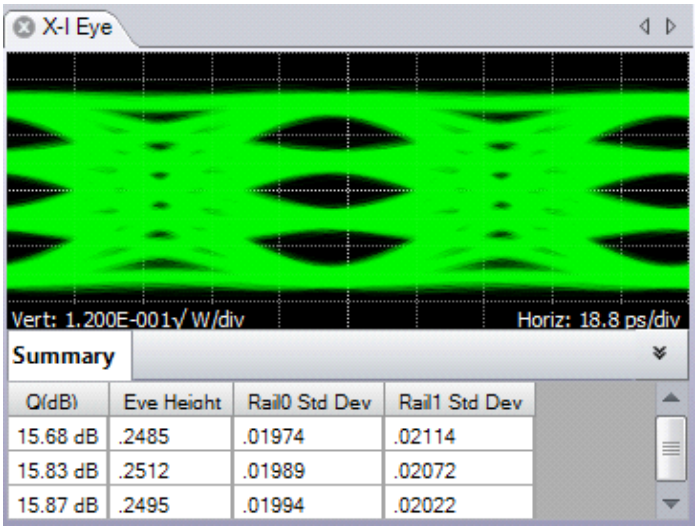
Color Key Constellation Points is a special feature that works when not in Color Grade. In this case the symbol color is determined by the value of the previous symbol. This helps reveal pattern dependence. Here it shows that pattern dependence is to blame for the poor EVM on the other groups. The modulator nonlinearity would normally mask this type of pattern dependence due to RF cable loss, but here the improper modulator bias is allowing that to be transferred to the optical signal.



Color Key Constellation – If the prior symbol was in Quadrant 1 (upper right) then the current symbol is colored Yellow. If the prior symbol was in Quadrant 2 (upper left) then the current symbol is colored Magenta. If the prior symbol was in Quadrant 3 (lower left) then the current symbol is colored Light Blue (Cyan). If the prior symbol was in Quadrant 4 (lower right) then the current symbol is colored Solid Blue.

Eye diagrams

Eye diagram plots can be selected for appropriate modulation formats. Supported eye formats include Field Eye, which is simply the real part of the phase trace in the complex plane, Power Eye which simulates the eye displayed with a Tektronix oscilloscope optical input, and Diff-Eye, which simulates the eye generated by using a 1-bit delay-line interferometer. As with the Constellation Plot you can right-click to choose color options as well. The Field Eye diagram provides the following measurements:



Field eye diagram.

Field eye measurements

Measurement	Description
Q (dB)	Computed from 20 × Log10 of the linear decision threshold Q-factor of the eye
Eye Height	The distance from the mean 1-level to the mean 0-level (units of plot)
Rail0 Std Dev	The standard deviation of the 0-level as determined from the decision threshold Q-factor measurement
Rail1 Std Dev	The standard deviation of the 1-level as determined from the decision threshold Q-factor measurement

In the case of multilevel signals, the above measurements are listed in the order of the corresponding eye openings in the plot. The top row values correspond to the top-most eye opening.

The above functions involving Q-factor use the decision threshold method described in the paper by Bergano [2]. When the number of bit errors in the measurement interval is small, as is often the case, the Q-factor derived from the bit error rate may not be an accurate measure of the signal quality. However, the decision threshold Q-factor is accurate because it is based on all the signal values, not just those that cross a defined boundary.

Additional measurements available for nonoffset formats

Measurement	Description
Overshoot	The fractional overshoot of the signal. One value is reported for the tributary, and for a multilevel (QAM) signal it is the average of all the overshoots
Undershoot	The fractional undershoot of the signal (overshoot of the negative-going transition)
Risetime	The 10-90% rise time of the signal. One value is reported for the tributary, and for a multilevel (QAM) signal it is the average of all the rise times
Falltime	The 90-10% fall time of the signal
Skew	The time relative to the center of the power eye of the midpoint between the crossing points for a particular tributary
Crossing Point	The fractional vertical position at the crossing of the rising and falling edges

Measurements vs. Time

In addition to the eye diagram, it is often important to view signals versus time. For example, it is instructive to see what the field values were doing in the vicinity of a bit error. All of the plots which display symbol-center values will indicate if that symbol is errored by coloring the point red (assuming that the data is synchronized to the indicated pattern). The Measurement vs. Time plot is particularly useful in this way as it helps to distinguish errors due to noise, pattern dependence, or pattern errors.

Errored symbol in Measurement vs. Time plot.

2 N.S. Bergano, F.W. Kerfoot, C.R. Davidson, “Margin measurements in optical amplifier systems,” IEEE Phot. Tech. Lett., 5, no. 3, pp. 304-306 (1993).

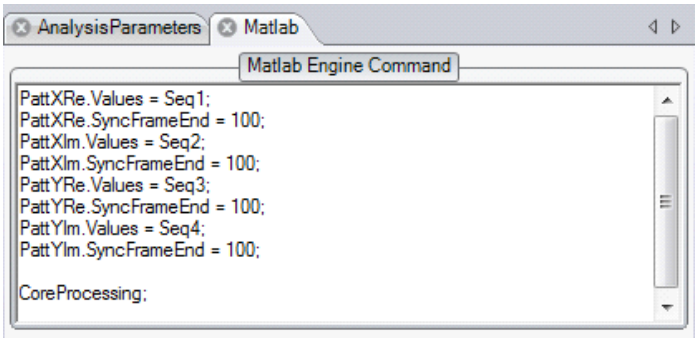
3D visualization tools

Complex-modulation signals are inherently 3D since in-phase and quadrature components are being changed vs. time. The 3D Eye Diagram provides a helpful combination of the Constellation and Eye diagrams into a single 3D diagram. This helps to visualize how the complex quantity is changing through the bit period. The diagram can be rotated and scaled.

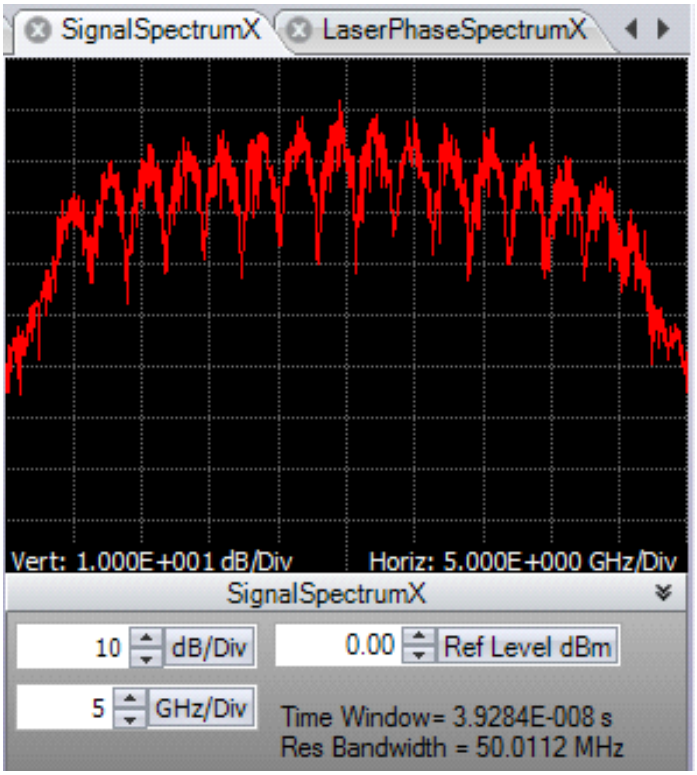
Also available in 3D is the Poincaré Sphere. The 3D view is helpful when viewing the polarization state of every symbol. The symbols tend to form clusters on the Poincaré Sphere which can be revealing to expert users. The non-normalized Stokes Vectors can also be plotted in this view.

Analysis Controls

The Analysis Controls window allows you to set parameters relevant to the system and its measurements.



MATLAB window.



Signal Spectrum window.

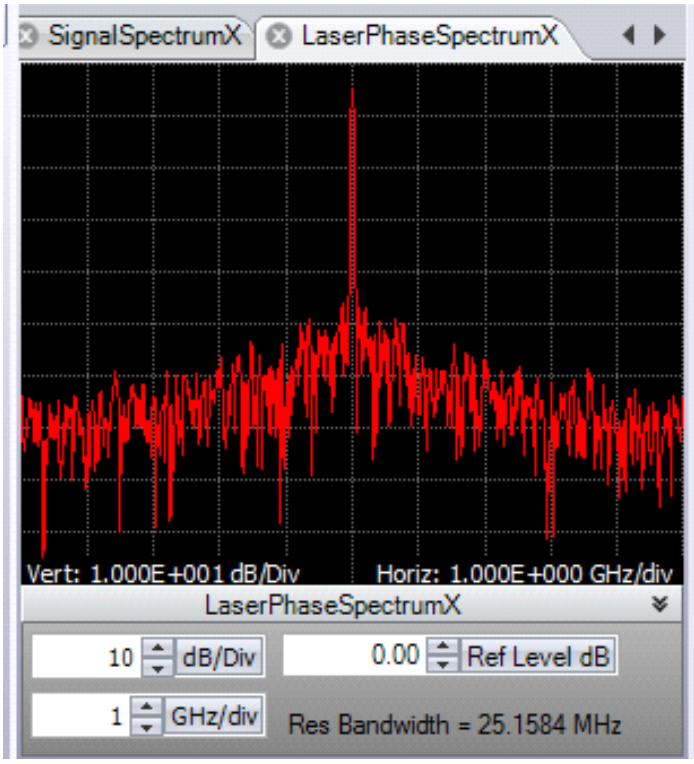
Analysis parameters

Parameter	Description
Frequency	Clock recovery is performed in software, so only a frequency range of expected clock frequencies is required
Signal Type	The signal type (such as PM-QPSK) determines the algorithm used to process the data
Data Patterns	Specifying the known PRBS or user pattern by physical tributary permits error counting, constellation orientation, and two-stage phase estimation

User patterns may be assigned in the MATLAB window shown here. The data pattern can be input into MATLAB or found directly through measurement of a high SNR signal.

Signal spectra

An FFT of the corrected electric field vs. time can reveal much about the data signal. Asymmetric or shifted spectra can indicate excessive laser frequency error. Periodicity in the spectrum shows correlation between data tributaries. The FFT of the laser phase vs. time data can be used to measure laser phase noise.

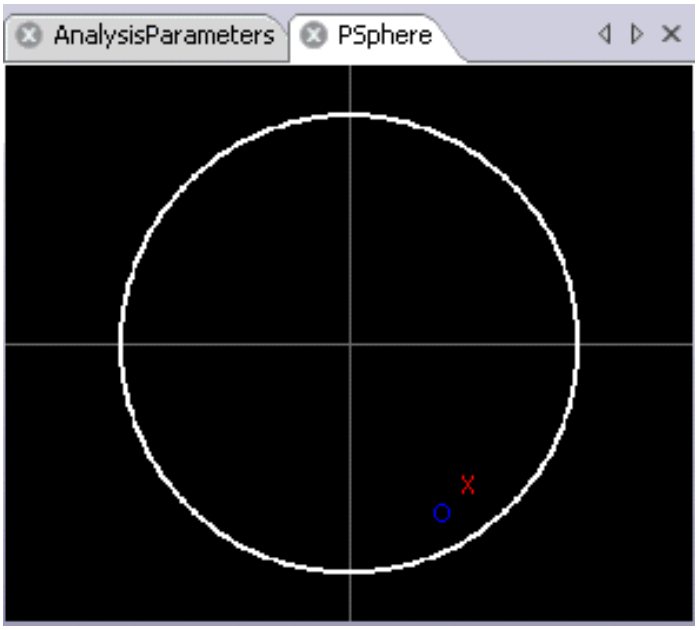


Laser Phase Spectrum window

Poincaré Sphere

Polarization data signals typically start out well aligned to the PM-fiber axes. However, once in standard single mode fiber, the polarization states will start to drift. However, it is still possible to measure the polarization states and determine the polarization extinction ratio. The software locks on each polarization signal. The polarization states of the two signals are displayed on a circular plot representing one face of the Poincaré sphere. States on the back side are indicated by coloring the marker blue. The degree of orthogonality can be visualized by inverting the rear face so that orthogonal signals always appear in the same location with different color. So, Blue means back side (negative value for that component of the Stokes vector), X means X-tributary, O means Y-tributary, and the Stokes vector is plotted so that left, down, blue are all negative on the sphere.

InvertedRearFace – Checking this box inverts the rear face of the Poincaré sphere display so that two orthogonal polarizations will always be on top of each other.



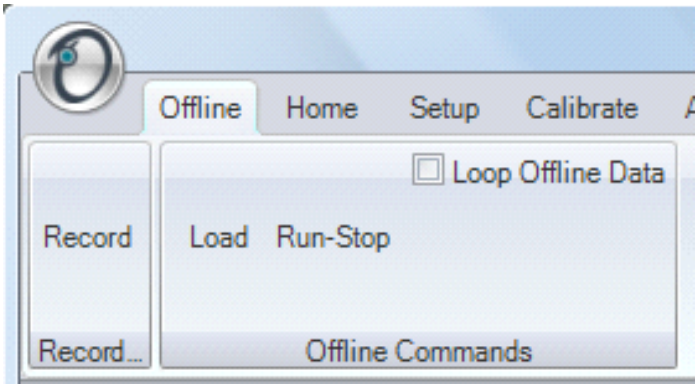
Poincaré Sphere window.

Impairment measurement and compensation

When studying transmission implementations, it is important to be able to compensate for the impairments created by long fiber runs or optical components. Chromatic Dispersion (CD), and Polarization Mode Dispersion (PMD) are two important linear impairments that can be measured or corrected by the OM4000 software. PMD measurement is based on comparison of the received signal to the back-to-back transmitter signal or to an ideal signal. This produces a direct measure of the PMD instead of estimating based on adaptive filter behavior. The user can specify the number of PMD orders to calculate. Accuracy for 1st-order PMD is ~1 ps at 10 Gbaud. There is no intrinsic limit to the CD compensation algorithm. It has been used successfully to compensate for many thousands of ps/nm.

Recording and playback

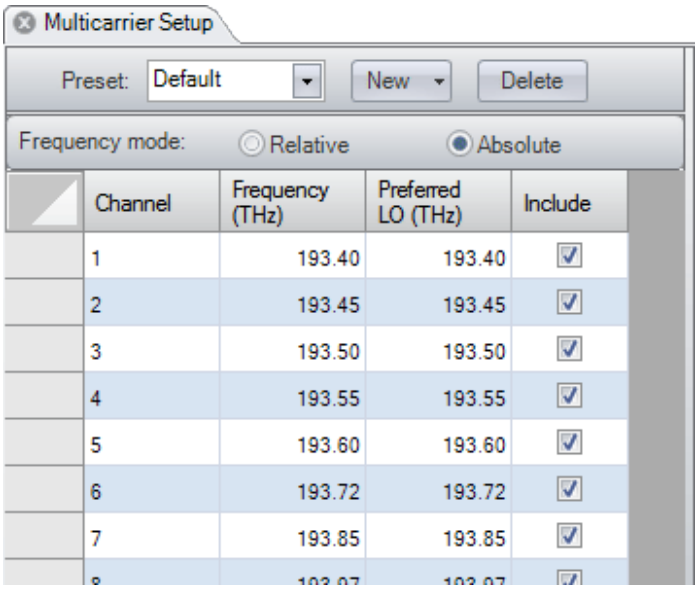
You can record the workspace as a sequence of .MAT files using the Record button in the Offline ribbon. These files are recorded in a default directory, usually the MATLAB working directory, unless previously changed. You can play back the workspace from a sequence of .MAT files by first using the Load button in the Offline Commands section of the Home ribbon. Load a sequence by marking the files you want to load using the Ctrl key and marking the filenames with the mouse. You can also load a contiguous series using the Shift key and marking the first and last filenames in the series with the mouse. Use the Run button in the Offline Commands section of the Home ribbon to cycle through the .MAT files you recorded. All filtering and processing you have implemented occurs on the recorded files as they are replayed.



Workspace record and playback.

Multi-carrier superchannel support

Even as 100G coherent optical systems are being deployed, architectures for 400G and beyond are being proposed and developed. One architecture gaining prominence is the “superchannel.” The configurations of superchannels vary considerably. Some proposals call for 400G to be achieved by 2 carriers of DP-16QAM. Other proposals are for 500 Gb/s consisting of 10 or more carriers of DP-QPSK. Some of these carriers are arranged on a standard ITU carrier grid, while others support 12.5 GHz “grid-less” layouts. Clearly, flexible test tools are needed for such next-generation systems. Option MCS to the OM4106D and OM1106 offers the complete flexibility to carrier out such tests.



Channel	Frequency (THz)	Preferred LO (THz)	Include
1	193.40	193.40	☑
2	193.45	193.45	☑
3	193.50	193.50	☑
4	193.55	193.55	☑
5	193.60	193.60	☑
6	193.72	193.72	☑
7	193.85	193.85	☑

Multi-carrier setup.

Multicarrier Measurements

Measurement	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Unit
X - Eye						
X-Q Q-Factor	15.473	16.526	14.576	16.350	14.654	dB
X-Q Eye Height	31.528	31.555	31.530	31.551	31.574	√mW
X-Q Rail 0 Std Dev	2.644	2.769	2.691	2.591	2.438	√mW
X-Q Rail 1 Std Dev	2.665	2.765	2.661	2.667	2.753	√mW
X-I Q-Factor	21.796	20.111	22.668	21.419	22.648	dB
X-I Eye Height	28.743	28.504	28.658	28.515	28.661	√mW
X-I Rail 0 Std Dev	1.239	1.216	1.043	1.281	1.161	√mW
X-I Rail 1 Std Dev	1.099	0.901	1.131	1.283	1.040	√mW
Y - Eye						
X - Const						
Y - Const						
Yconst IQ Imbalance	1.006	1.006	1.006	1.007	1.006	
Yconst Bias, Real	0.07	0.05	0.09	0.06	0.01	%
Yconst Bias, Imag	-0.03	-0.02	-0.01	-0.04	-0.01	%
Yconst Phase Angle	90.19	90.19	90.18	90.17	90.17	deg
Yconst Magnitude	22.079	22.072	22.097	22.099	22.091	√mW
Yconst EVM, Average	15.01	14.09	14.33	14.95	16.16	%
Yconst Mask Violat...	0	5	5	12	-3	
Yconst Symbols Dis...	2992	2992	2992	2992	2992	
Yconst Symbol Std....	0.074	0.072	0.069	0.070	0.069	√mW
X - Trans						
Y - Trans						
Pow - Trans						
XY Measurements						
PMD						

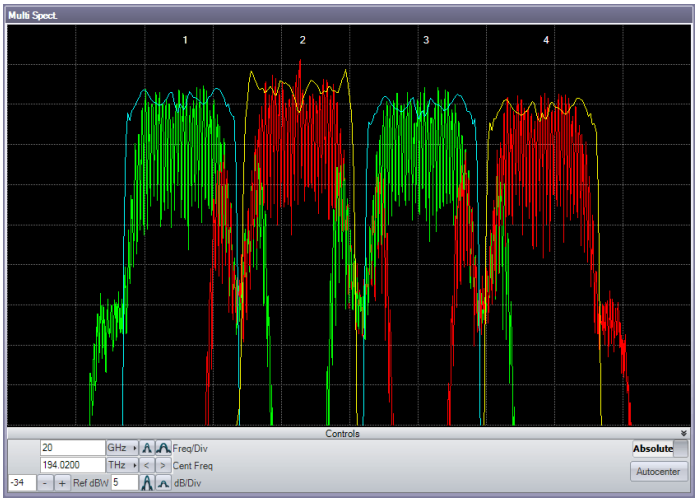
Clear Statistics

Multi-carrier measurements.

User-definable superchannels

For manufacturers getting a jump on superchannels, or researchers investigating alternatives, user-definable superchannel configurations are a must. Option MCS allows the user to set up as many carriers within the superchannel definition as necessary. Each carrier can have an arbitrary center frequency; no carrier grid spacing is imposed. The carrier center frequencies can be set as absolute values (in THz) or as relative values (in GHz).

Typically, the OUI will retune the OM4106D local oscillator for each carrier. However, in cases where multiple carriers may fit within the oscilloscope bandwidth, multiple carriers can be demodulated in software from a common local oscillator frequency. The user is given the flexibility to specify the preferred local oscillator frequency for each carrier.



Superchannel spectrum.

Automated measurements

Once the superchannel is configured, the system can take measurements on each channel without further intervention by the user. The OUI automatically tunes the OM4106D local oscillator, takes measurements at that channel, re-tunes to the next channel, and so forth until measurements of the entire superchannel have been taken. Results of each channel are displayed in real-time and persist after all measurements are made for easy comparison.

Integrated measurement results

All of the same measurement results that are made for single channels are also available for individual channels in a superchannel configuration. Additionally, multi-carrier measurement results are available side-by-side for comparison between channels. Visualizations such as eye diagrams, constellation diagrams, and optical spectrum plots can be viewed a single channel at a time, or with all channels superimposed for fast comparison. For separating channels in a multi-carrier group, several different filters can be applied, including raised cosine, Bessel, Butterworth, Nyquist, and user-defined filters. These filters can be any order or roll-off factor and track the signal frequency.

Coherent optical signal generation

Tektronix offers several signal generation instruments capable of generating coherent optical waveforms. The AWG70000 Series Arbitrary Waveform Generators (AWG) and the PPG3000 Series Programmable Pattern Generators offer the flexibility to choose the type of signal generation instrument suited to the test requirements.

The AWG70000 Series can reach sampling rates as high as 50GSa/s with 10 bits vertical resolution. This level of performance allows for the direct generation of IQ basebands signals required by modern coherent optical communication systems. The arbitrary waveform generation capabilities of the AWG70000 Series makes it possible to create multi-level signals such as 16QAM or 64QAM, add impairments to a signal, or to create waveforms that are pre-compensated for the real-world effects of the test system.

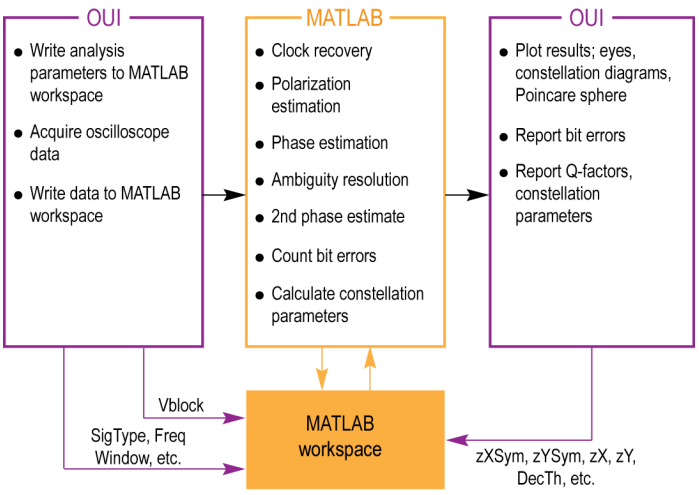
The PPG3000 Series can generate patterns up to 32 Gb/s and offers 1, 2, or 4 channels in a single instrument. The patterns can be standard PRBS patterns or user-defined. Using a 4-channel pattern generator makes creating dual-polarization I-Q waveforms very simple.

Coherent optical signal generation is one of the more demanding applications for an AWG. The requirements in terms of number of channels sampling rate, bandwidth, record length, and timing and synchronization quality can be only met by the highest performance instruments, such as the Tektronix AWG70000 series. The unique capability of generating ideal or distorted signals, and the ease to add new modulation schemes and signal processing algorithms without the need to add any extra hardware, make AWGs an ideal tool for coherent optical communication research and development.

Interaction between OUI and MATLAB

The OUI takes information about the signal provided by the user together with acquisition data from the oscilloscope and passes them to the MATLAB workspace, shown in Figure 3. A series of MATLAB scripts are then called to process the data and produce the resulting field variables. The OUI then retrieves these variables and plots them. Automated tests can be accomplished by connecting to the OUI or by connecting directly to the MATLAB workspace.

The user does not need any familiarity with MATLAB; the OUI can manage all MATLAB interactions. However, advanced users can access the MATLAB interface internal functions to create user-defined demodulators and algorithms, or for custom analysis visualization.



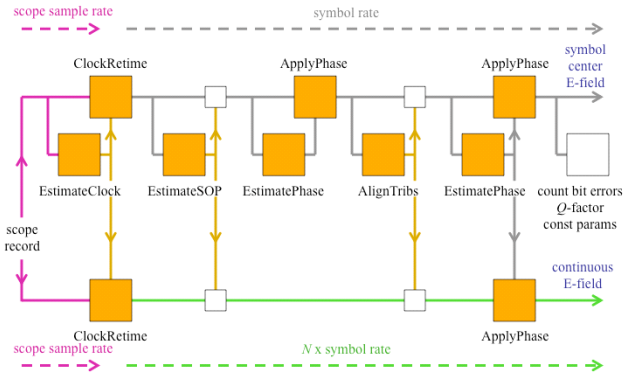
OUI/MATLAB data flow

Signal processing approach

For real-time sampled systems, the first step after data acquisition is to recover the clock and retime the data at 1 sample per symbol at the symbol center for the polarization separation and following algorithms (shown as upper path in the figure). The data is also re-sampled at 10X the baud rate (user settable) to define the traces that interconnect the symbols in the eye diagram or constellation (shown as the lower path).

The clock recovery approach depends on the chosen signal type. Laser phase is then recovered based on the symbol-center samples. Once the laser phase is recovered, the modulation part of the field is available for alignment to the expected data for each tributary. At this point bit errors can be counted by looking for the difference between the actual and expected data after accounting for all possible ambiguities in data polarity. The software selects the polarity with the lowest BER. Once the actual data is known, a second phase estimate can be done to remove errors that may result from a laser phase jump. Once the field variables are calculated, they are available for retrieval and display by the OUI.

At each step the best algorithms are chosen for the specified data type, requiring no user intervention unless desired.



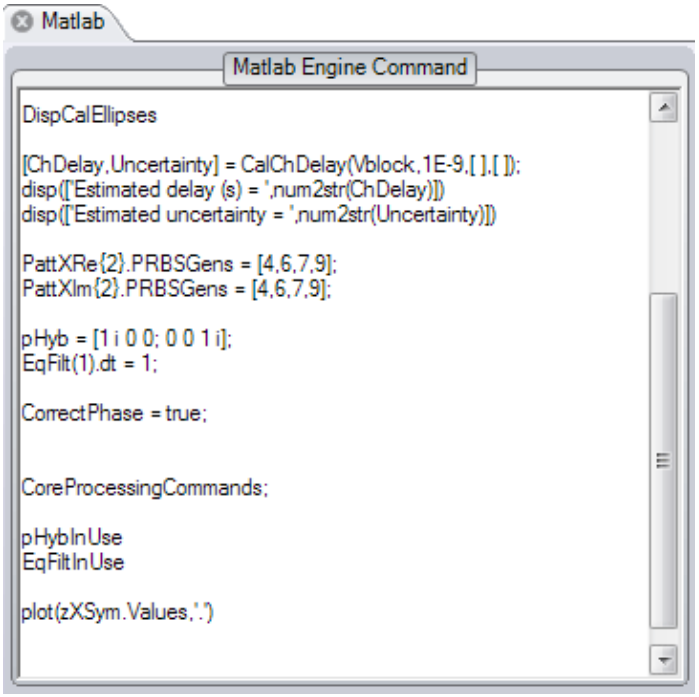
Data flow through the “Core Processing” engine.

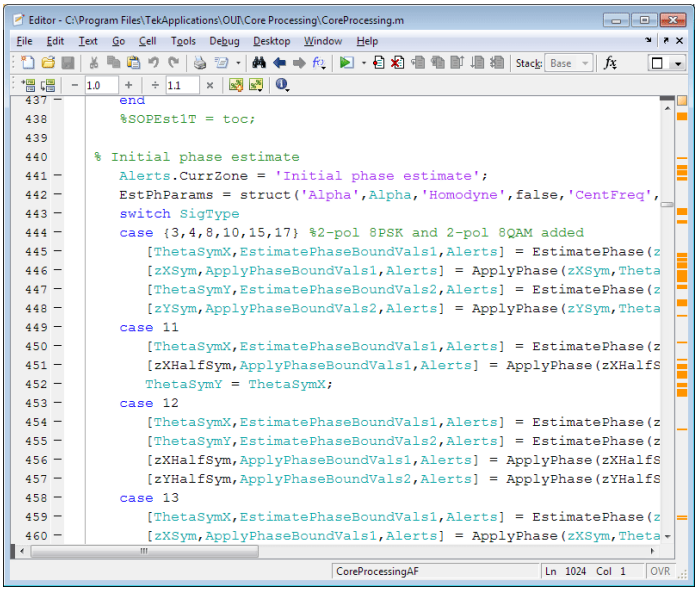
Signal processing customization

The OM1106 software includes the MATLAB source code for the "CoreProcessing" engine (certain proprietary functions are provided as compiled code). You can customize the signal processing flow, or insert or remove processes as desired. Alternatively, you can remove all Tektronix processing and completely replace it with your own. By using the existing variables defined for the data structures, you can then see the results of analysis processing using the rich visualizations provided by the OUI. This allows you to focus your time on algorithms rather than on tasks such as acquiring data from the oscilloscope or displaying constellation diagrams.

Dynamic MATLAB integration

Customizing the CoreProcessing algorithms provide an excellent way conduct signal processing research. In order to speed up development of signal processing the OM-Series User Interface (OUI) provides a dynamic Matlab integration window. Any Matlab code typed in this window is executed on every pass through the signal processing loop. This allows you to quickly add or "comment out" function calls, write specific values into data structures, or modify signal processing parameters on the fly without having to stop the processing loop or modify the Matlab source code.





CoreProcessing functions

The following are some of the CoreProcessing functions used to analyze the coherent signal. Full details on these functions, their use in the processing flow, and the MATLAB variable used, are available in the OM1106 user manual.

- **EstimateClock** determines the symbol clock frequency of a digital data-carrying optical signal based on oscilloscope waveform records. The scope sampling rate may be arbitrary (having no integer relationship) compared to the symbol rate.
- **ClockRetime** forms an output parameter p, representing a dual-polarization signal vs. time, from four oscilloscope waveforms V. The output p is retimed to be aligned with the timing grid specified by Clock.
- **EstimateSOP** reports the state of polarization (SOP) of the tributaries in the optical signal. The result is provided in the form of an orthogonal (rotation) matrix RotM. For a polarization multiplexed signal the first column of RotM is the SOP of the first tributary, and the second column the SOP of the second tributary. For a single tributary signal, the first column is the SOP of the tributary, and the second column is orthogonal to it. The signal is transformed into its basis set (the tributaries horizontal vertical polarizations) by multiplying by the inverse of RotM.
- **EstimatePhase** estimates the phase of the optical signal. The algorithm used is known to be close to the optimal estimate of the phase. The algorithm first determines the heterodyne frequency offset and then estimates the phase. The phase reported in the .Values field is after the frequency offset has been subtracted.
- **ApplyPhase** multiplies the values representing a single or dual polarization parameters vs. time by a phase factor to give a resulting set of values.
- **AlignTribs** performs ambiguity resolution. The function acts on variable which is already corrected for phase and state of polarization, but for which the tributaries have not been ordered. AlignTribs uses the data content of the tributaries to distinguish between them. AlignTribs processes the data patterns in order according to the modulation format, starting with X-I. For each pattern it tries to match the given data pattern with the available tributaries of the signal. If the same pattern is used for more than one tributary, the relative pattern delays will be used to distinguish between them.

  The use of delay as a secondary condition to distinguish between tributaries means that AlignTribs will work with transmission experiments that use a single data pattern generator which is split several ways with different delays. The delay search is performed only over a limited range of 1000 bits in the case of PRBS patterns, so this method of distinguishing tributaries will not usually work when using separate data pattern generators programmed with the same PRBS.
- **Spect** estimates the power spectral density of the optical signal using a discrete Fourier transform. It can take any many of our time waveforms as input such as corrected oscilloscope input data, front-end processed data, polarization separated data, averaged data, and FIR data. It can also apply Hanning or Flat-Top window filters and produce the desired resolution bandwidth over a set frequency range.
- **GenPattern** generates a sequence of logical values, 0s and 1s, given an exact data pattern. The exact pattern specifies not only the form of the sequence but also the place it starts and the data polarity. The data pattern specified may be a pseudo-random bit sequence (PRBS) or a specified sequence.
- **LaserSpectrum** estimates the power spectral density of the laser waveform in units of dBc. The function LaserSpectrum takes ThetaSym, the estimated relative laser phase sampled at the symbol rate, as input and defines the frequency centered laser waveform. This waveform is then scaled by a hamming window, and the power spectral density of the waveform is estimated as the discrete Fourier transform of this signal.
- **QDecTh** uses the decision threshold method to estimate the Q-factor of a component of the optical signal. The method is useful because it quickly gives an accurate estimate of Q-factor (the output signal-to-noise ratio) even if there are no bit errors, or if it would take a long time to wait for a sufficient number of bit errors.

Supported measurements and display tools

Characteristic	Description	Real-time supported feature	Equivalent time supported feature
Constellation Diagram	Constellation diagram accuracy including intradyne and demodulation error can be measured by the RMS error of the constellation points divided by the magnitude of the electric field for each polarization signal	X	X
Constellation Elongation	Ratio of constellation height to width	X	X
Constellation Phase Angle	Measure of transmitter IQ phase angle	X	X
Constellation I and Q Bias	Measure of average symbol position relative to the origin	X	X
Constellation Mask	User-settable allowed EVM level. Symbols violating the mask are counted	X	X
Eye Decision Threshold Q-factor	The actual Q achieved will depend on the quality of the data signal, the signal amplitude, and the oscilloscope used for digitalization. Using the Tektronix DPO73304D oscilloscope (4-Ch), a Q-factor of 20 dB is achievable at 40 GBaud	X	X

Characteristic	Description	Real-time supported feature	Equivalent time supported feature
Decision Threshold Q-plot	Displays BER vs. decision threshold for each eye opening. The Q value at optimum decision threshold is the Q-factor	X	X
Signal Spectrum and Laser Spectrum	Display of signal electric field vs. time in the complex plane FFT of power signal or laser phase noise	X	
MATLAB Window	Commands may be entered that execute each time signals are acquired and processed	X	X
Measurements vs. Time	Optical field, symbol-center values, errors, and averaged waveforms are displayed vs. time in the OUI; any parameter can be plotted vs. time using the appropriate MATLAB expression	X	X
3D Measurements	3D Eye (complex field values vs. time), and 3D Poincaré Sphere for symbol and tributary polarization display	X	
Differential Eye Diagram Display	Balanced or single-ended balanced detection is emulated and displayed in the Differential Eye Diagram	X	
Frequency Offset	Frequency offset between signal and reference lasers is displayed in Measurement panel	X	
Poincarè Sphere	Polarizations of the Pol-muxed signal tributaries are tracked and displayed on the Poincaré Sphere. PER is measured	X	X
Signal Quality	EVM, Q-factor, and mask violations	X	X
Tributary Skew	A time offset for each tributary is reported in the Measurement panel	X	X
CD Compensation	No intrinsic limit for offline processing – FFT-based filter to remove CD in frequency domain based on a given dispersion value	X	
PMD Measurement	PMD values are displayed in the Measurement panel for Polarization-multiplexed formats with a user-specified number of PMD orders	X	
Oscilloscope and/or Cable Delay Compensation	Cable, oscilloscope, and receiver skew is corrected through interpolation in the OUI. Additional cable adjustment is available using the oscilloscope UI	±0.5 ns	
Oscilloscope Skew Adjustment	Equivalent-time oscilloscope skew is adjusted using the "Delay" feature in the supported sampling head plug-ins		±100%
Calibration Routines	Receiver Skew, DC Offset, and Path Gain Mismatch Hybrid angle and state of polarization are factory calibrated	X	X
Data Export Formats	MATLAB (other formats available through MATLAB or ATE interface); PNG	X	X
Raw Data Replay with Different Parameter Setting	Movie mode and reprocessing	X	X
Bit Error Ratio Measurements	Number of counted bits/symbols	X	X
	Number or errors detected	X	X
	Bit error ratio	X	X
	Differential-detection errors	X	X
	Save acquisition on detected error	X	X
Offline Processing	Run software on a separate PC or on the oscilloscope	X	X
Coherent Eye Diagram	Shows the In-Phase or Quadrature components vs. time modulo two bit periods.	X	X
Power Eye Diagram	Shows the computed power per polarization vs time modulo 2 bit periods.	X	X

System requirements

Supported platforms for the OM1106 software (OUI):

- Computer with nVidia graphics card running US Windows 7 64-bit and MATLAB 2011b (64-bit)
- Computer with nVidia graphics card running US Windows XP 32-bit and MATLAB 2009a (32-bit)

The following platforms are supported but may not be able to use certain advanced graphics features such as color grade and 3D:

- Tektronix 70000 Series Oscilloscopes running Windows 7 64-bit and MATLAB 2011b (64-bit)
- Computer with non-nVidia graphics running US Windows 7 64-bit and MATLAB 2011b (64-bit)
- Computer with non-nVidia graphics running US Windows XP 32-bit and MATLAB 2009a (32-bit)

Please check with Tektronix when ordering for the most up-to-date requirements including support for the latest releases of MATLAB software.

Please contact Tektronix for a price quote or to arrange a demonstration. All product descriptions and specifications are subject to change without notice.

Ordering information

Signal analyzer software

OM1106	Coherent Lightwave Signal Analyzer software

OM1106 options

OM1106	OUI signal analysis software only
OM1106 QAM	Adds QAM and other software demodulators
OM1106 MCS	Adds multi-carrier superchannel support
OM1106 L0	English manual
OM11UP	Upgrade kits to the Coherent Lightwave Signal Analyzer Software:
OM11UP MCS	Adds Multi-carrier (superchannel) support
OM11UP QAM	Adds QAM and other software demodulators
OM11UP SHIP	Customer Requests Shipment or Export Requirement
OMADDLSW	Adds additional seat of Coherent Lightwave Signal Analyzer Software

Related products

23 GHz optical modulation analyzer

OM4006D	23 GHz Coherent Lightwave Signal Analyzer (requires choice of lasers)
OM4006D CC	C-band lasers (receiver tested over C-band)
OM4006D LL	L-band lasers (receiver tested over L-band)
OM4006D CL	Coupled C- and L-band lasers (receiver calibrated over Cand L-band)
OM4006D NL	No lasers (receiver calibrated over C- and L-band)
OM4006D EXT	Adds external connections for reference laser
OM406D QAM	Adds QAM and other software demodulators
OM4006D MCS	Adds multi-carrier superchannel support

33 GHz optical modulation analyzer

OM4106D	33 GHz Coherent Lightwave Signal Analyzer (requires choice of lasers):
OM4106D CC	C-band lasers (receiver tested over C-band)
OM4106D LL	L-band lasers (receiver tested over L-band)
OM4106D CL	Coupled C- and L-band lasers (receiver calibrated over Cand L-band)
OM4106D NL	No lasers (receiver calibrated over C- and L-band)
OM4106D EXT	Adds external connections for reference laser
OM4106D QAM	Adds QAM and other software demodulators
OM4106D MCS	Adds multi-carrier superchannel support

Coherent optical transmitter

OM5110	46 GBaud Dual-Polarization Coherent Optical IQ Transmitter
OM5110 C	C-band laser factory installed
OM5110 L	L-band laser factory installed
OM5110 NL	No laser installed, requires external laser

Coherent receiver calibration source

OM2210	33 GHz Coherent Lightwave Signal Analyzer (requires choice of lasers):
OM2210 C	C-Band Coherent Receiver Calibration Source (with single C-band laser)
OM2210 CC	C-Band Coherent Receiver Calibration Source (with two C-band lasers)
OM2210 L	L-Band Coherent Receiver Calibration Source (with single L-band laser)
OM2210 LL	L-Band Coherent Receiver Calibration Source (with two L-band lasers)
OM2210 CL	C + L-Band Coherent Receiver Calibration Source (with coupled C and L lasers)
OM2210 NL	Receiver calibrated over C+L

C-Band & L-Band laser sources

OM2012	nLaser (requires choice of laser configuration):
OM2012 CC	C-Band nLaser (with two C-band lasers)
OM2012 CL	C + L-Band nLaser (with one C-band laser and one L-band laser)
OM2012 LL	L-Band nLaser (with two L-band lasers)

Tektronix is registered to ISO 9001 and ISO 14001 by SRI Quality System Registrar.

Product Area Assessed: The planning, design/development and manufacture of electronic Test and Measurement instruments.

ASEAN / Australasia (65) 6356 3900
Belgium 00800 2255 4835*
Central East Europe and the Baltics +41 52 675 3777
Finland +41 52 675 3777
Hong Kong 400 820 5835
Japan 81 (3) 6714 3010
Middle East, Asia, and North Africa +41 52 675 3777
People's Republic of China 400 820 5835
Republic of Korea 001 800 8255 2835
Spain 00800 2255 4835*
Taiwan 886 (2) 2656 6688

Austria 00800 2255 4835*
Brazil +55 (11) 3759 7627
Central Europe & Greece +41 52 675 3777
France 00800 2255 4835*
India 000 800 650 1835
Luxembourg +41 52 675 3777
The Netherlands 00800 2255 4835*
Poland +41 52 675 3777
Russia & CIS +7 (495) 6647564
Sweden 00800 2255 4835*
United Kingdom & Ireland 00800 2255 4835*

Balkans, Israel, South Africa and other ISE Countries +41 52 675 3777
Canada 1 800 833 9200
Denmark +45 80 88 1401
Germany 00800 2255 4835*
Italy 00800 2255 4835*
Mexico, Central/South America & Caribbean 52 (55) 56 04 50 90
Norway 800 16098
Portugal 80 08 12370
South Africa +41 52 675 3777
Switzerland 00800 2255 4835*
USA 1 800 833 9200

* European toll-free number. If not accessible, call: +41 52 675 3777

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13 Jan 2015 85W-31037-0

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